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Forecasting the 10-Hour Timelag Fuel Moisture

Rocky Mountain Forest and
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Forest Service
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Abstract

A procedure for forecasting the 10-hour timelag fuel moisture was developed from the theory of diffusion in wood. Studies of fuel moisture processes relating meteorological variables, as an external force, to moisture exchange processes in wood are combined here to provide a forecasting aid for the 10-hour timelag fuel moisture. Tables developed for field use were validated with data from a field study. Detailed step-by-step instructions and related tables are provided.

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Contents

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Introduction

Fuel moisture is the most important variable in determining fire ignition potential and energy output from fires. It is almost as important as wind in determining the rate of spread and the fireline intensity of wildfires. The National Fire Danger Rating System (Deeming et al. 1972) introduced specific fuel sizes and characteristics, each requiring accurate quantitative assessment of current and forecast fuel moisture. The intent of this Paper is to utilize the full knowledge of fuel moisture calculations in order to provide a means of assessing current and forecast fuel moisture. Very early, fire researchers recognized the importance of fuel moisture, and carried out classic studies on fuel moisture and climate (Gisborne 1928, 1933a, 1933b, 1936; Hayes 1941, 1944). These studies established the basic concepts of measuring fire weather and fire danger.

Once fire danger could be determined, foresters began to recognize the need for forecasts of fire danger (i.e., fire weather) so that short range plans could be made for potential control efforts. Forecasts now assume a major role in fire management discussions. However, while foresters know the current situations, they also need to know potential conditions. Major economic decisions must be made every day based on weather forecasts.

Statistical relationships between meteorological variables and fuel moisture were developed during the 1930's and various systems were available for field use by the 1960's (Byram 1940, 1943; Jemison 1935; Storey 1965). Unfortunately, each time fire danger rating procedures were modified, many statistical relationships required revisions. Also, while there were many techniques available, each had limited geographic applicability. In the 1960's, fire management agencies decided to support development of a national fire danger rating system which would be updated periodically. Fuel moisture research to support this system was aimed at providing general relationships between meteorology and fuel moisture that could be applied uniformly on a national basis.

Basic Concepts of Fuel Moisture Calculations

First efforts to develop a general model for fuel moisture were based on a diffusion theory in wood (Byram[2], Fosberg 1970, 1972). These solutions defined the moisture exchange processes in wood in detail, but treated the atmosphere only superficially. They did define the interface between fuel moisture and atmospheric processes in sufficient detail, however, to allow the transfer of the fundamental research to field applications. Basic diffusion processes and related wood properties were defined by Stamm (1946) and first applied to fuel moisture problems by Byram. Fosberg (1970) adapted Byram's solutions to fire weather variables of temperature and relative humidity. Fosberg (1971, 1972) then carried this analysis further to include a changing environment (diurnal and seasonal changes in temperature and humidity) as well as influence of precipitation on fuel moisture. Key developments in adapting wood technology to fuel moisture were Byram's use of the timelag concept in fuel moisture calculations, and Fosberg's (1971, 1972) introduction of meteorological variables (the changing environment and the precipitation effects) as boundary conditions.

Byram defined timelag as the time interval required for the fuel moisture to change 1−1/e (or approximately 2/3) of the difference between a uniform starting equilibrium value to a new uniform equilibrium after the environment was changed instantaneously. Here e is the base of the Naperian logarithms. Figure 1 illustrates a fuel with a 10-hr timelag. In a constant environment, it would take about 50 hr before it achieved a value near the new equilibrium. This process with a constant environment can be readily achieved

[2]*Byram, George M. 1963. An analysis of the drying process in forest fuel materials. Paper presented at the 1963 International Symposium on humidity and moisture. Wash., D.C. May 20-23, 1963. 38 p.*

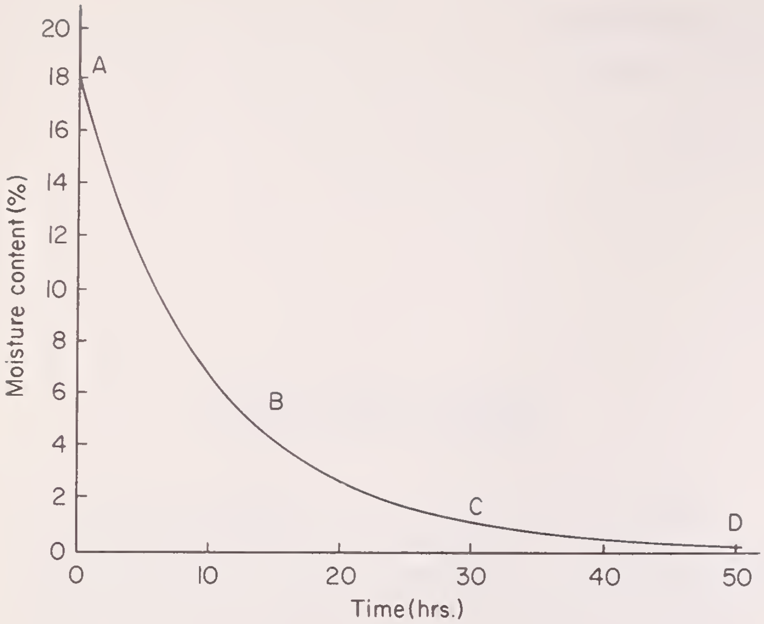

Figure 1.—Basic timelag concept. At point A, fuel moisture is uniformly 18%. At hr 0, the environment is suddenly changed so that a new equilibrium of 0% moisture content exists. The fuel responds slowly to this change so that after 10 hr (point B) the fuel has lost 11% of its moisture (2/3 of the difference between the old and new equilibrium conditions). At 20 hr (point C) it is 8/9 of the way to the new equilibrium, and at 50 hr (point D) it is nearly at equilibrium (Fosberg 1970).

in the laboratory. The basic equation describing this process is:

$$\frac{\delta m}{\Delta m} = \frac{m - m_i}{m_e - m_i} = 1 - e^{-t/\tau} \qquad [1]$$

where δm is the actual moisture change over the time interval t, Δm is the potential moisture change (the difference between the two equilibrium values, and τ is the timelag). The variables m, m_i, and m_e are the moisture content at a given time t, the starting equilibrium value and the final equilibrium value. Using figure 1, a 10-hr timelag fuel ($\tau = 10$) starting at an equilibrium value of 18% ($m_i = 18$) with a dry environment ($m_e = 0$) has a potential change of 18% ($\Delta m = m_e - m_i = 0 - 18 = -18$). The actual change at 10 hr is $\delta m = m - 0 = -18\ (1 - e^{-10/10}) = -11$, so the moisture content after 10 hr is 7%.

The equilibrium of potential moisture content is dependent on the temperature and humidity in the immediate vicinity of the fuel. Basic relationships between temperatures, relative humidity, and potential moisture content are defined in the Wood Handbook (USDA Forest Service 1974) and are readily calculated from equations presented by Simard (1968). These functions in degrees F, percent relative humidity, and percent moisture content are:

$$\text{emc} = 0.03229 + 0.281073h - 0.000578hT \text{ for } h < 10\% \qquad [2a]$$

$$\text{emc} = 2.22749 + 0.160107h - 0.014784T \text{ for } 11\% < h < 50\% \qquad [2b]$$

$$\text{emc} = 21.0606 + 0.005565h^2 - 0.00035hT - 0.483199h \text{ for } h > 50\% \qquad [2c]$$

The relationship between equilibrium moisture content, temperature, and humidity is shown in figure 2.

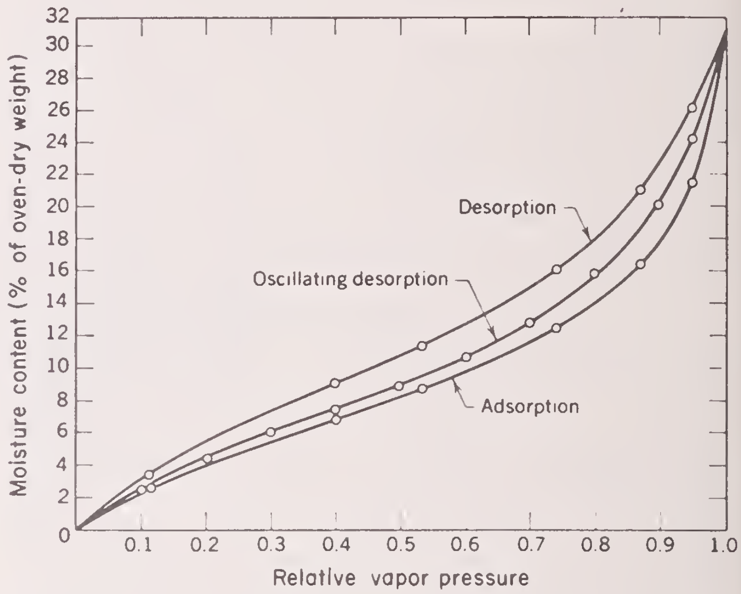

Figure 2.—Equilibrium moisture content isotherms for wood (Alfred J. Stamm, "Wood and Cellulose Science", copyright ©1964, The Ronald Press Company, New York).

Equilibrium moisture contents are a result of water sorption due to free energy differences between free water molecules and water loosely bound to the cellulose molecules in wood.

Uptake of moisture from precipitation by fuels is limited by the sorption rate of wood. Diffusion of water into wood is very slow (10^{-7}cm^2/sec) compared to atmospheric processes (0.2 cm^2/sec). The difference in diffusion rates (10^6) accounts for the slower response of fuels to atmospheric changes and is represented by the timelag. Both theoretical and laboratory analyses indicate that rainfall rates in excess of 1 mm/hr do not increase the wetting of fuels (Fosberg 1972). More important is the length of time the fuels are exposed to the rainfall, or, if they lie on the ground where water can form puddles, the time this liquid environment is present. While liquid water influences follow the exponential process both within the wood and as a surface boundary condition, the surface boundary condition (the tie to meteorology) can

be treated as a linear function of precipitation duration as a first approximation. The major effect of the precipitation is contained in the constant of the linear function. This function

$$m_e = a + bt \qquad [3]$$

defines the new potential moisture content for equation [1]. The constant term, a, may be as low as 15% for fine fuels to as high as 76% for heavy fuels.[3] The time-dependent term, b, varies between 0.5 and 2.7%/hr for rainfall rates in excess of 1 mm/hr. This time-dependent rate variation is due to exposed surface area of the fuels and water surface tension control of rundown and drip. The time-dependent term is much less significant than the constant term if rain falls as showers with measurable precipitation. If the precipitation requires many hours to reach measurable amounts, the duration term could be most important. Thus, a gentle rain lasting for several days and producing only a ½ in would be more effective in wetting fuel than a 3-in downpour from a thunderstorm lasting only 20 or 30 min.

All of the foregoing discussions of fuel moisture changes have been based on the concept that once the environment has changed, it will stay that way until the fuel reaches the new equilibrium. In reality, the environment is constantly changing. Temperature and humidity change on regular diurnal and seasonal bases. Temperature, humidity, and precipitation also depend on synoptic scale flow patterns. These continuous changes of meteorological variables require that equations describing fuel moisture change account for the changing environment.

Different fuels respond at different rates to environmental changes. Fast response or short timelag fuels—such as fine twigs and needles—will follow atmospheric changes very closely, while intermediate fuels—such as ½-in diameter sticks and 1-in logs—will respond at a slower rate. Heavy fuels—such as 6-in diameter logs or larger (1,000-hr timelags)—show very little response to diurnal changes, but are responsive to seasonal changes.

To illustrate this response, consider the 1-, 10- and 100-hr timelag fuels of the National Fire Danger Rating System (Deeming, et al. 1972). The ratio of response to diurnal changes (fig. 3) shows a sharp drop in amplitude compared to the potential change as this timelag increases.

[3]Fosberg, Michael A. Unpublished research on file at Rocky Mt. For. and Range Exp. Stn. Preliminary results presented in Fosberg (1972). 15% is most appropriate for the 10-hr fuel.

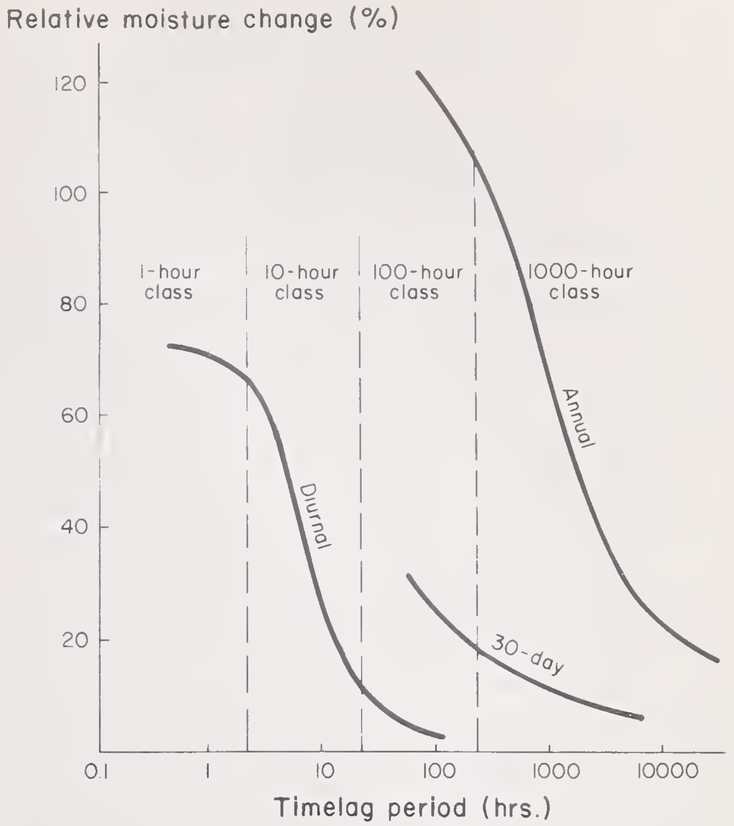

Figure 3.—Percentage of potential response realized by fuels as a function of timelag (Lancaster 1970; Fosberg 1971).

Also, maximum and minimum fuel moisture values lag behind the potential or equilibrium value (fig. 4). This lag exists because fuels respond slowly and, until the potential drops to the fuel moisture level defined by ambient conditions and below (or rises to the level and above), the fuel moisture will continue to decrease (or increase). Even though fine fuel moisture has begun to fall early in the morning, the intermediate and heavy fuels will continue to take on moisture (although at a slower rate) until the potential fuel moisture drops below the current moisture content of the individual fuel.

The basis for applying the timelag concepts to field situations where the environment is constantly changing involves only the introduction of an environmental coefficient in equation [1] (the basic exponential change). The additional coefficient enters equation [1] as the term ζ in the environmentally dependent equation (Fosberg 1972):

$$\frac{\delta m}{\Delta m} = \frac{m - m_i}{m_b - m_i} = 1 - \zeta e^{-t/\tau} \qquad [4]$$

Here m_b replaces m_e to include precipitation effects as well as equilibrium moisture. The term m_b contains both the temperature- and humidity-

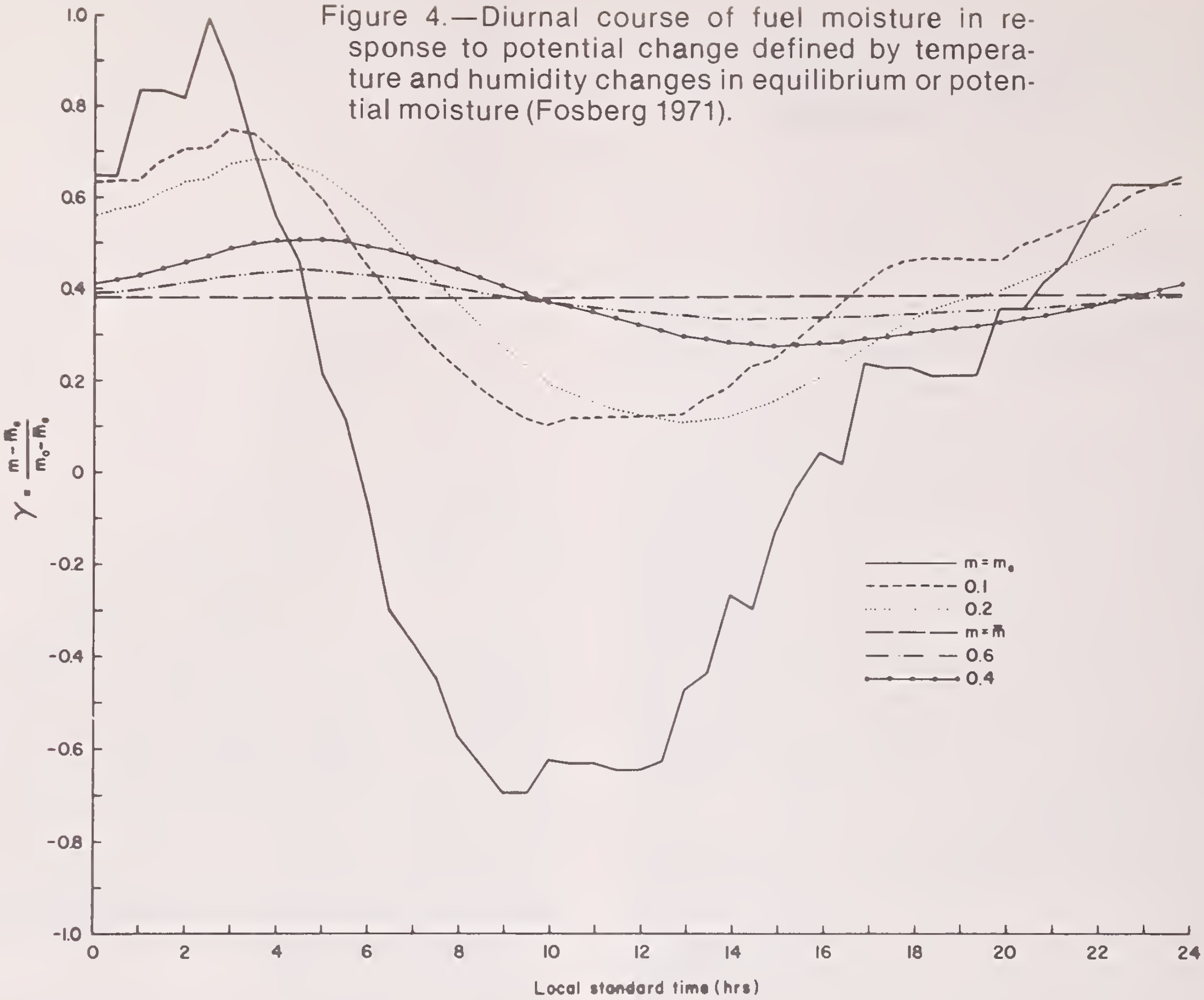

Figure 4.—Diurnal course of fuel moisture in response to potential change defined by temperature and humidity changes in equilibrium or potential moisture (Fosberg 1971).

dependent equilibrium moisture as well as the influence of rainfall on the external boundary conditions. This basic environmentally dependent equation forms the basis of current fuel moisture analysis and prediction technology.

The following section will cover the technology of defining the environmental effects on the boundary condition (m_b of equation [4]) and the coefficient (ζ) which is dependent on antecedent conditions. If the environment is constant, $\zeta = 1$ and the solution is defined by equation [1]. If the internal moisture is not uniformly distributed, or if the environment is changing, $\zeta \neq 1$.

The environmental coefficient, ζ, was examined in detail by Haltiner (1975) and found to have a pronounced diurnal pattern (fig. 5). At night, $\zeta > 1$, indicating a slower moisture response than under laboratory conditions when the fuel is taking up moisture. During daytime drying, $\zeta < 1$, indicating a faster response than the laboratory condition. These preliminary estimates of ζ are not fully verified and the amplitude of the curve may be excessive.

The above procedures for introducing meteorology into the fuel moisture predictions all assume that the observations are made in the immediate vicinity of the fuel. In reality, temperature

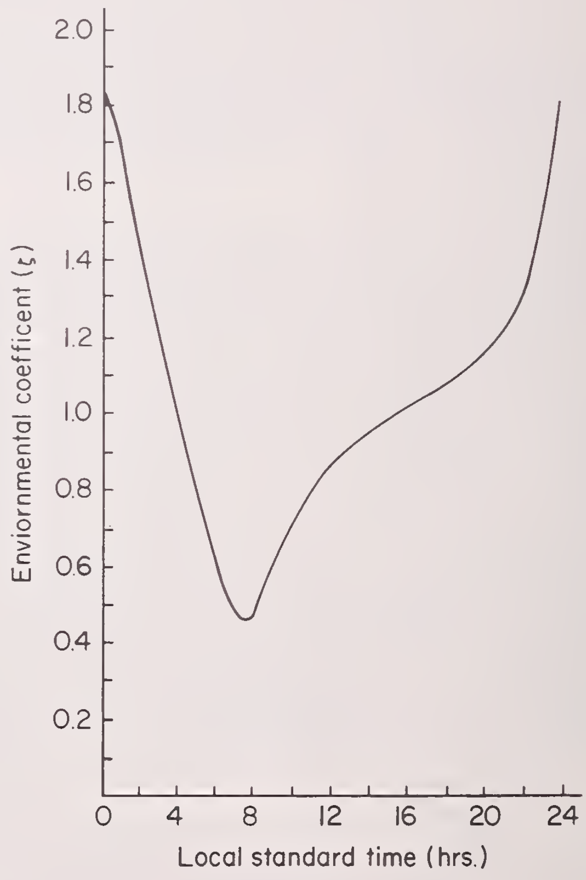

Figure 5.—Diurnal variation of the environmental coefficient of equation [4] (Haltiner 1975).

and humidity observations are made in a screen 4 ft above the ground, while the fuels (in particular, the ½-in diameter sticks) are exposed 10 in above the ground in the open. Radiation loading on the fuels changes their microenvironment from that measured in the instrument shelter. Byram (1940) proposed the function

$$h_f = h_a \frac{e_a}{e_f} \qquad [5]$$

to correct the shelter relative humidity to the relative humidity at the fuel. In equation [5], h_f is the relative humidity at the fuel level, h_a is the relative humidity in the screen, e_a is the saturation vapor pressure of the shelter air, and e_f is the saturation vapor pressure described by the fuel temperature. Preliminary results (Haltiner 1975) indicate that the fuel temperature is about 3 to 5°C warmer than the shelter temperature between 1200 LST and 1600 LST, and 0 to 1°C cooler just before sunrise on clear days. On cloudy days, both the incoming short wave radiation and the outgoing long wave radiation would be reduced, and the fuel temperature (and therefore the local environment) would be much closer to the shelter readings. As an example, consider a shelter temperature of 82°F with 20% humidity. The fuel temperature would be 4°C (8°F) warmer, so the relative humidity influencing the fuel would be:

$$h_f = 20\% \ \frac{e_a\,(82\,°F)}{e_f\,(90\,°F)} = 20 \ \frac{1.1017}{1.4219} = 16\%.$$

The saturation vapor pressures are taken from the Smithsonian Meteorological Tables (List 1966).

Shelter readings must also be corrected to account for the wind influences on the microenvironment of the fuels. Basically, windspeed controls the depth of the thermal and moisture boundary layers. Under light winds, the temperature of the fuel will remain higher than that in the shelter. Also, the humidity boundary layer will be dominated by the moisture in the fuel. Preliminary results indicate that wind effect on the microenvironment becomes important when the standard 20 ft windspeed exceeds 15-20 mph (Haltiner 1975). Above this threshold, the relative humidity near the fuels can be approximated by the shelter reading, since the boundary layer effect will be reached.

A Model to Predict the 10-Hour Timelag Fuel Moisture

The 10-hr timelag fuel experiences large diurnal changes in moisture content (figs. 3 and 4) and has only a small carryover from the previous day. Diurnal change in moisture content must be accounted for in the calculations, even though fire danger interest concerns the midafternoon forecast only. This model is structured to meet fire danger forecasting needs, since that is the major use. The model could be adapted to other fire management needs without major changes. The basic structure of the applied model is based on equations [2], [3], [4], and [5] and the coefficient described in figure 5 of the preceding section.

To account for nighttime moisture uptake, the 24-hr forecast period is divided into two periods—1400 LST today until 0600 LST tomorrow morning, and from 0600 LST tomorrow morning until 1400 LST tomorrow afternoon (the verification time). The procedure is to forecast the 0600 LST temperature and humidity, correct it for radiation effects [equation 5], and then calculate the potential moisture content [equation 2]. This forecast potential moisture content would then be corrected for precipitation effects [equation 3], and would enter equation [4] as the potential moisture content (m_b). A 0600 LST moisture content would be predicted based on m_i, the current 1400 LST value of fuel moisture. The environmental coefficient, ζ, would be determined from figure 5. This procedure is repeated, using the 0600 LST forecast fuel moisture as the starting value (m_i). The forecast 1400 LST temperature and humidity, corrected for radiation is used to obtain a forecast afternoon potential fuel moisture, which is then corrected for precipitation. The potential fuel moisture and the 0600 LST fuel moisture are then used to solve equation [4] with the environmental coefficient (fig. 5) to forecast fuel moisture for tomorrow afternoon (1400 LST). This procedure can be simplified for forecast purposes by serially solving the equation. Schematically, this can be illustrated by a flow diagram (fig. 6).

The general flow chart can be condensed significantly by rearranging equation [4] so that the intermediate forecast (${}^{6}m$) for 0600 is:

$${}^{6}m = {}^{T}m + ({}^{6}m_b - {}^{T}m)\,(1 - {}^{6}\zeta \exp(-16/10)) \qquad [6a]$$

and the forecast for tomorrow afternoon (${}^{14}m$) is:

$${}^{14}m = {}^{6}m + ({}^{14}m_b - {}^{6}m)\,(1 - {}^{14}\zeta \exp(-8/10)) \qquad [6b]$$

where ${}^{6}m_b$ and ${}^{14}m_b$ are the forecast potential fuel moistures, ${}^{T}m$ is the current 1400 LST fuel mois-

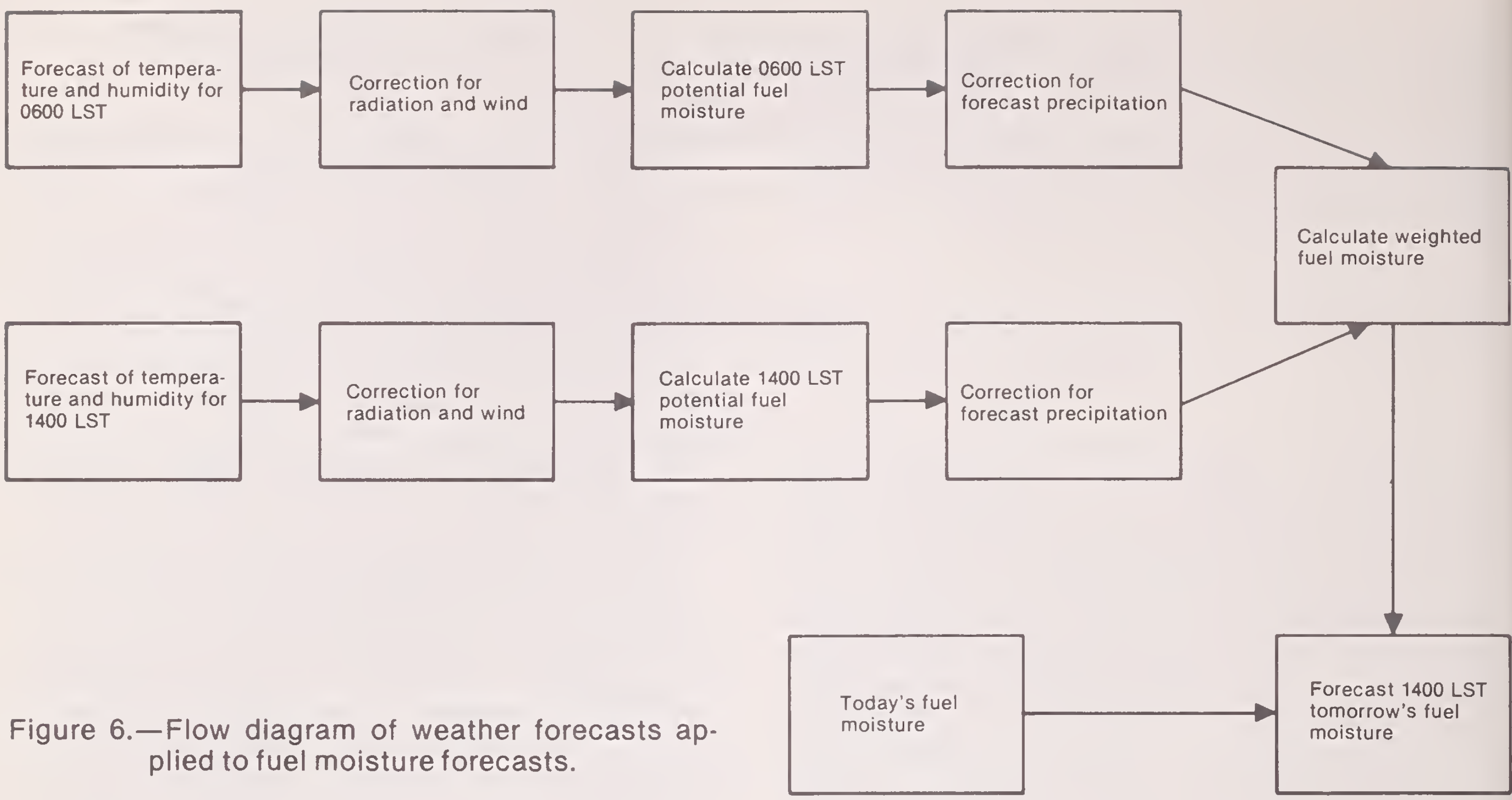

Figure 6.—Flow diagram of weather forecasts applied to fuel moisture forecasts.

ture, $^6\zeta$ and $^{14}\zeta$ are the environmental coefficients at 0600 and 1400, and the exponential terms reflect the 16 hr from 1400 today to 0600 tomorrow and 0600 tomorrow to 1400 tomorrow, both divided by the 10-hr timelag. Using figure 5, $^6\zeta$ is 1.1 and $^{14}\zeta$ is 0.87. Combining equations [6a] and [6b] and collecting terms to calculate the 1400 LST forecast fuel moisture gives:

$$^{14}m = {}^{T}m\,(1 - {}^{6}\chi - {}^{14}\chi + {}^{14}\chi\,{}^{6}\chi) + {}^{6}m_b({}^{6}\chi - {}^{6}\chi\,{}^{14}\chi) + {}^{14}m_b\,{}^{14}\chi$$

where: $^{6}\chi = 1 - 1.1 \exp(-1.6)$

and $^{14}\chi = 1 - 0.87 \exp(-0.8)$

or, in a simplified form:

$$^{14}m = a\,{}^{T}m + b\,{}^{6}m_b + c\,{}^{14}m_b \qquad [7]$$

where the coefficients are $a = 0.09$, $b = 0.30$, and $c = 0.61$.

Since the value of a is small, today's moisture content will influence the forecast only if today's fuel moisture is above 10% (a 1% carryover of residual moisture since $a = 0.09$). While b is only half of c, the value of $^{6}m_b$ is generally large compared to the value of $^{14}m_b$ and therefore must be included. An error in the 0600 forecast is only half as detrimental as an error in the 1400 forecast, however.

Procedures for Forecasting the 10-Hour Fuel Moisture

The flow of the weather forecast leading to a fuel moisture forecast described in figure 6 can be reduced to three tables for fuel moisture, and one table and an equation to correct the shelter readings to fuel levels. Forecast fuel moisture is obtained by a 10-step procedure.

Table 1 corrects for the radiation loading by providing the saturation vapor pressure used in the humidity correction ratio [equation 5].

$$h_f = h_a \frac{e_a(\text{shelter})}{e_f(\text{air at fuel level})}$$

The three tables for fuel moisture are based on (1) calculating the potential fuel moisture (table 2 is a tabulated solution to equation [2]) and (2) determining weighted fuel moisture. The two inputs to table 3 are the 0600 and 1400 potential fuel moisture used to obtain the weighted fuel moisture, defined by the 2nd and 3rd terms of equation [2]. Since table 3 contains timelag terms as well as the two potential moistures, the table values provide a solution to the moisture equation if the residual carryover is small. The third fuel moisture table (table 4) introduces the residual effect of today's moisture content (if above 10%) into tomorrow's forecast value.

Specific steps in forecasting the 10-hr timelag fuel moisture are:

Table 1.—Saturation vapor pressure over water

Temperature	Saturation vapor pressure	Temperature	Saturation vapor pressure	Temperature	Saturation vapor pressure
°F	In Hg	°F	In Hg	°F	In Hg
0	.04477	50	.36240	100	1.9334
1	.04691	51	.37611	101	1.9923
2	.04915	52	.39028	102	2.0529
3	.05149	53	.40492	103	2.1149
4	.05392	54	.42003	104	2.1786
5	.05646	55	.43564	105	2.2440
6	.05910	56	.45176	106	2.3110
7	.06185	57	.46840	107	2.3798
8	.06471	58	.48558	108	2.4503
9	.06769	59	.50330	109	2.5226
10	.07080	60	.52160	110	2.5968
11	.07403	61	.54047	111	2.6728
12	.07740	62	.55994	112	2.7507
13	.08089	63	.58002	113	2.8306
14	.08454	64	.60073	114	2.9125
15	.08832	65	.62209	115	2.9963
16	.09226	66	.64411	116	3.0823
17	.09634	67	.66681	117	3.1703
18	.10060	68	.69021	118	3.2606
19	.10501	69	.71432	119	3.3530
20	.10960	70	.73916	120	3.4477
21	.11437	71	.76476	121	3.5446
22	.11933	72	.79113	122	3.6439
23	.12446	73	.81829	123	3.7455
24	.12980	74	.84626	124	3.8496
25	.13534	75	.87506	125	3.9561
26	.14109	76	.90472	126	4.0651
27	.14705	77	.93524	127	4.1768
28	.15324	78	.96666	128	4.2910
29	.15966	79	.99900	129	4.4078
30	.16631	80	1.0323	130	4.5274
31	.17321	81	1.0665	131	4.6498
32	.18036	82	1.1017	132	4.7750
33	.18778	83	1.1380	133	4.9030
34	.19546	84	1.1752	134	5.0340
35	.20342	85	1.2136	135	5.1679
36	.21166	86	1.2530	136	5.3049
37	.22020	87	1.2935	137	5.4450
38	.22904	88	1.3351	138	5.5881
39	.23819	89	1.3779	139	5.7345
40	.24767	90	1.4219	140	5.8842
41	.25748	91	1.4671	141	6.0371
42	.26763	92	1.5136	142	6.1934
43	.27813	93	1.5613	143	6.3532
44	.28899	94	1.6103	144	6.5164
45	.30023	95	1.6607	145	6.6832
46	.31185	96	1.7124	146	6.8536
47	.32387	97	1.7655	147	7.0277
48	.33629	98	1.8200	148	7.2056
49	.34913	99	1.8759	149	7.3872

Table 2.—Potential fuel moisture, as a function of relative humidity and temperature

Relative humidity	Temperature, °F							
	30	40	50	60	70	80	90	100
	%							
5	1.5	1.5	1.5	1.5	1	1	1	1
10	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
15	4	4	4	3.5	3.5	3.5	3.5	3
20	5	5	4.5	4.5	4.5	4	4	4
25	6	5.5	5.5	5.5	5	5	5	5
30	6.5	6.5	6.5	6	6	6	5.5	5.5
35	7.5	7	7	7	7	6.5	6.5	6.5
40	8	8	8	7.5	7.5	7.5	7.5	7
45	9	9	8.5	8.5	8.5	8	8	8
50	10	9.5	9.5	9.5	9	9	9	9
55	11	11	10	10	10	10	10	9
60	12	11	11	11	11	10	10	10
65	12	12	12	12	12	11	11	11
70	14	14	14	14	12	12	12	12
75	16	16	14	14	14	14	14	14
80	18	16	16	16	16	16	16	16
85	20	20	18	18	18	18	18	18
90	22	22	22	20	20	20	20	20
95	24	24	24	24	24	22	22	22
100	28	28	26	26	26	26	26	24

1. Forecast the 0600 LST temperature and humidity.
2. Correct the shelter forecast to account for radiation and wind influences as microclimate (table 1 provides saturation vapor pressures).
3. Enter table 2 to find potential fuel moisture from the corrected temperature and humidity.
4. Correct the 0600 LST potential fuel moisture forecast for precipitation. If measurable precipitation will occur during the period 1400 LST today until 0600 tomorrow, add 15% to the potential fuel moisture for this period (result of step 3).
5. Forecast the 1400 LST temperature and humidity.
6. Correct the shelter forecast for radiation and wind influences on fuel microclimate (with table 1).
7. Enter table 2 to find the potential fuel moisture for 1400.
8. Correct the potential fuel moisture by adding 15% if measurable precipitation is forecast for the period 0600 tomorrow to 1400 tomorrow (result of step 7).
9. Enter table 3 with the results of the 0600 forecast (step 4) and the 1400 forecast (step 8) to arrive at the weighted fuel moisture. If today's fuel moisture is less than 10%, this weighted fuel moisture is the forecast for tomorrow. If the fuel moisture for today is above 10% use table 4 to account for residual fuel moisture (step 10).
10. Enter today's fuel moisture and the weighted fuel moisture from step 9 into table 4 to account for residual carryover of wet fuels. When fuels are wet, this step accounts for residual effects in drying.

As an example to illustrate the procedure, consider the following set of conditions:

1.	Current 10-hr timelag fuel moisture.	7%
2.	0600 tomorrow temperature forecast	64°F

Table 3.—Weighted fuel moisture, as a function of predicted potential fuel moisture at 0600 and 1400 LST

Predicted potential fuel moisture 0600 LST	Predicted potential fuel moisture — 1400 LST															
	1	1.5	2	2.5	3	3.4	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5
%																
1	1	1	1.5	2	2	2.5	2.5	3	3.5	3.5	4	4.5	4.5	5	5	5.5
1.5	1	1.5	1.5	2	2.5	2.5	3	3	3.5	4	4	4.5	4.5	5	5.5	5.5
2	1	1.5	2	2	2.5	3	3	3.5	3.5	4	4	4.5	5	5	6	6
2.5	1.5	1.5	2	2.5	2.5	3	3	3.5	4	4	4.5	4.5	5	5.5	5.5	6
3	1.5	2	2	2.5	3	3	3.5	3.5	4	4.5	4.5	5	5	5.5	6	6
3.5	1.5	2	2.5	2.5	3	3.5	3.5	4	4	4.5	4.5	5	5.5	5.5	6	6
4	2	2	2.5	2.5	3	3.5	4	4	4.5	4.5	5	5	5.5	6	6	6.5
4.5	2	2.5	2.5	3	3	3.5	4	4.5	4.5	4.5	5	5.5	5.5	6	6	6.5
5	2	2.5	2.5	3	3.5	3.5	4	4.5	5	5	5	5.5	6	6	6.5	6.5
5.5	2.5	2.5	3	3	3.5	4	4	4.5	5	5.5	5.5	5.5	6	6	6.5	7
6	2.5	2.5	3	3.5	3.5	4	4.5	4.5	5	5.5	6	6	6	6.5	6.5	7
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7	2.5	3	3.5	3.5	4	4.5	4.5	5	5	5.5	6	6	7	7	7	7.5
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8.5	3.5	3.5	4	4	4.5	4.5	5	5.5	5.5	6	6	6.5	7	7.5	8	8.5
9	3.5	3.5	4	4.5	4.5	5	5	5.5	6	6	6.5	6.5	7	7.5	8	8.5
9.5	3.5	4	4	4.5	4.5	5	5.5	5.5	6	6	6.5	7	7	7.5	8	8.5
10	3.5	4	4.5	4.5	5	5	5.5	6	6	6.5	6.5	7	7.5	7.5	8	8.5
11	3.5	4	4.5	4.5	5	5.5	5.5	6.5	6	6.5	6.5	7	7.5	7.5	8	8.5
12	4	4.5	5	5	5.5	6	6	6.5	6.5	7	7.5	7.5	8	8	8.5	9
14	4.5	5	5.5	6	6	6.5	6.5	7	7.5	7.5	8	8	8.5	9	9	9.5
16	5.5	6	6	6.5	6.5	7	7.5	7.5	8	8	8.5	9	9	9.5	10	10
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20	6.5	7	7.5	7.5	8	8	8.5	9	9	9.5	10	10	10	11	11	11
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36	11	12	12	12	12	14	14	14	14	14	14	14	16	16	16	16
38	11	12	12	14	14	14	14	14	14	14	16	16	16	16	16	16
40	12	14	14	14	14	14	14	14	16	16	16	16	16	16	18	18

	9	9.5	10	11	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
1	6	6	6.5	6.5	7	8	9	10	11	12	14	16	18	18	20	22	22	24	24
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3.5	6.5	7	7	8	8.5	9.5	11	12	14	14	16	16	18	20	20	22	24	24	26
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4.5	7	7	7.5	8	8.5	10	11	12	14	14	16	18	18	20	20	22	24	24	26
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10	9	9.5	10	10	10	12	12	14	16	16	18	18	20	22	22	24	24	26	28
11	9	9.5	10	11	11	12	12	14	16	16	18	18	20	22	22	24	24	26	28
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38	18	18	18	18	18	20	22	22	24	24	26	28	28	30	30	32	34	34	36
40	18	18	18	20	20	20	22	24	24	26	26	28	30	30	32	32	34	36	36

Table 4.—Predicted fuel moisture, as a function of weighted and current fuel moisture

Weighted fuel moisture	Current fuel moisture																
	≤10	11	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
					%												
1	2	2	2	2	2.5	2.5	2.5	3	3	3.5	3.5	3.5	4	4	4	4.5	4.5
1.5	2.5	2.5	2.5	2.5	3	3	3	3.5	3.5	4	4	4	4.5	4.5	4.5	5	5
2	3	3	3	3	3.5	3.5	3.5	4	4	4.5	4.5	4.5	5	5	5	5.5	5.5
2.5	3.5	3.5	3.5	3.5	4	4	4	4.5	4.5	5	5	5	5.5	5.5	5.5	6	6
3	4	4	4	4	4.5	4.5	4.5	5	5	5.5	5.5	5.5	6	6	6	6.5	6.5
3.5	4.5	4.5	4.5	4.5	5	5	5	5.5	5.5	6	6	6	6.5	6.5	6.5	7	7
4	5	5	5	5	5.5	5.5	5.5	6	6	6.5	6.5	6.5	7	7	7	7.5	7.5
4.5	5.5	5.5	5.5	5.5	6	6	6	6.5	6.5	7	7	7	7.5	7.5	7.5	8	8
5	6	6	6	6	6.5	6.5	6.5	7	7	7.5	7.5	7.5	8	8	8	8.5	8.5
5.5	6.5	6.5	6.5	6.5	7	7	7	7.5	7.5	8	8	8	8.5	8.5	8.5	9	9
6	7	7	7	7	7.5	7.5	7.5	8	8	8.5	8.5	8.5	9	9	9	9.5	9.5
6.5	7.5	7.5	7.5	7.5	8	8	8	8.5	8.5	9	9	9	9.5	9.5	9.5	10	10
7	8	8	8	8	8.5	8.5	8.5	9	9	9.5	9.5	9.5	10	10	10	10	11
7.5	8.5	8.5	8.5	8.5	9	9	9	9.5	9.5	10	10	10	10	11	11	11	11
8	9	9	9	9	9	9.5	9.5	10	10	10	10	10	11	11	11	11	12
8.5	9.5	9.5	9.5	9.5	10	10	10	10	11	11	11	11	11	11	12	12	12
9	10	10	10	10	10	11	11	11	11	11	11	12	12	12	12	12	12
9.5	10	10	11	11	11	11	11	11	12	12	12	12	12	12	12	12	14
10	10	10	11	11	11	12	12	12	12	12	12	12	12	14	14	14	14
11	11	11	12	12	12	12	12	14	14	14	14	14	14	14	16	16	16
12	12	12	14	14	14	14	14	14	14	14	14	14	14	16	16	16	16
14	14	14	16	16	16	16	16	16	16	16	16	16	18	18	18	18	18
16	16	16	16	16	18	18	18	18	18	18	18	18	18	20	20	20	20
18	18	18	18	18	20	20	20	20	20	20	20	20	20	22	22	22	22
20	20	20	20	20	20	20	20	20	22	22	22	22	22	24	24	24	24
22	22	22	24	24	24	24	22	22	24	24	24	24	24	26	26	26	26
24	24	24	24	24	24	24	24	24	24	26	26	26	26	28	28	28	28
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38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	40
40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40

3. 0600 tomorrow humidity forecast — 92%
4. 1400 today to 0600 tomorrow cloud cover forecast — Clear
5. 1400 today to 0600 tomorrow precipitation forecast — None
6. 1400 tomorrow temperature forecast — 96°F
7. 1400 tomorrow humidity forecast — 20%
8. 0600 tomorrow to 1400 tomorrow cloud cover forecast — Clear
9. 0600 tomorrow to 1400 tomorrow precipitation forecast — None

In the above example, the 0600 temperature and humidity are 64°F and 92% respectively. These values correspond to a 0600 potential moisture of 24% (table 2). The midafternoon forecast for 1400 is 96°F and 20% relative humidity. Since the sky is clear, the fuel temperature of 104°F and the adjusted relative humidity (using table 1) is:

$$h_f = \frac{e_a(96)}{e_f(104)}\,20 = \frac{1.7124}{2.1786}\,20 = 16\%.$$

Entering the 104°F and 16% relative humidity into table 2, the 1600 potential fuel moisture is 3%. The weighted fuel moisture for values of 24% and 3% is 9%. Since the current fuel moisture is 7%, table 4 is not needed and the forecast fuel moisture for 1400 tomorrow is 9%.

Accuracy of the Model

The forecast model was tested against meteorological and fuel moisture data taken at the Colorado State University weather station during the summer of 1971. These calculations assumed perfect temperature and humidity forecasts in that the verification data for temperature and humidity were used. These calculations were not corrected for radiation loading on the fuels. A comparison of the predicted fuel moisture against observed fuel moisture shows reasonable agreement (fig. 7). The model tended to forecast fuel moisture 1% to 2% higher than observed—a factor readily accounted for by the radiation loading—although stick-weathering may also be responsible.[4]

[4]*Johnson, Von J. December 2, 1976, personal correspondence.*

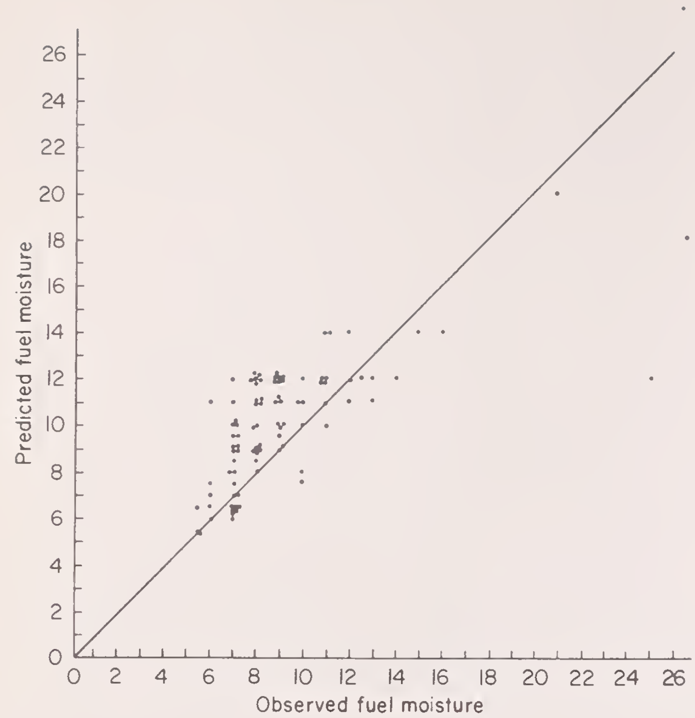

Figure 7.—Comparison of predicted and observed fuel moistures.

Summary

Procedures for forecasting the 10-hr timelag fuel moisture defined above are currently automated and the equations are solved in the AFFIRMS system (Helfman et al. 1975). These techniques allow the forecaster to directly forecast the 10-hr fuel moisture as an input to AFFIRMS rather than enter the maximum and minimum values of temperature and humidity, precipitation occurrence, and cloud cover. Also, requests for individual forecasts for individual fires and for nighttime fuel moisture can be made with these procedures.

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Keywords: Timelag, fuel moisture, fire weather.

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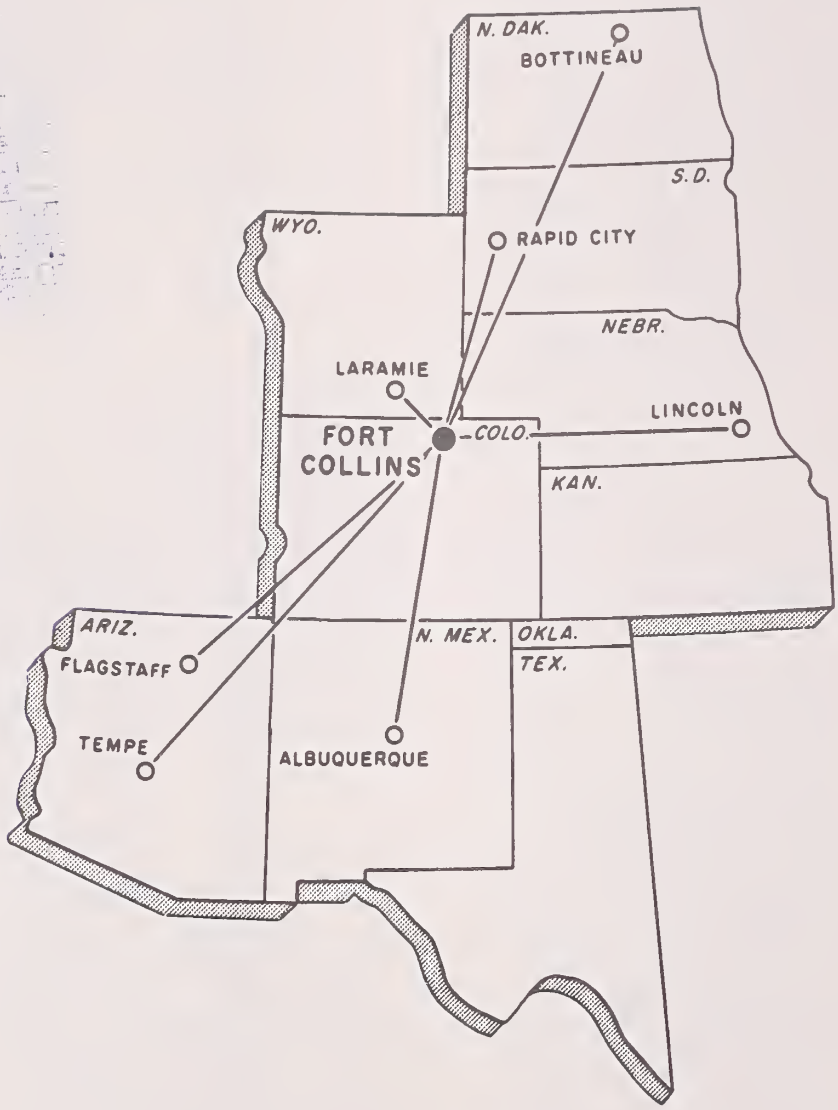
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